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CR-133768

ANALYSES AND APPLICATIONS OF MULTIPLE CYCLES OF ERTS-1 IMAGERY OVER COUNTY OF LOS ANGELES:

ASSESSMENT OF DATA UTILITY FOR URBAN DEVELOPMENT AND REGIONAL PLANNING

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(E73-10989) ANALYSES AND APPLICATIONS OF MULTIPLE CYCLES OF ERTS-1 IMAGERY OVER COUNTY OF LOS ANGELES: ASSESSMENT OF DATA UTILITY FOR URBAN (General Electric Co.) 16 p HC $3.00 CSCL 05B
N73-31295
G3/13 Unclas 00989

BIOGRAPHICAL SKETCHES

Mr. Surendra Raje, Systems Development Engineer in the Advanced NASA Programs, is principal investigator on the ERTS 1 Experiment SR 124 reported here. Dr. Richard Economy, Manager, Advanced Earth Observation Programs Information Systems, principally designed the GEMS/IMAGE 100 Electronic Multispectral Information Extraction Systems used in this investigation. Mr. Jene McKnight, Head, Planning Policies Section, is test site coordinator and primary user-analyst on the team. Mr. Darryl Goehring, Planning Consultant has a position in the COLA-RPC created for remote sensing applications. Mr. Gerald Willoughby, President, OVAAC8 International Inc. is a consultant specializing the urban design and regional planning services.

ABSTRACT

An overview of an ERTS Data Use investigation of test site SR 124, in Southern California, is presented. On describing formats of ERTS products and support aircraft imagery scales, data analysis tools, techniques and procedures are discussed. A user-evaluation of the General Electric Multispectral Information Extraction System (GEMS) is one of the primary investigation objectives, others being assessments of data content, utility of ERTS imagery and development of methodologies for regional planning and urban development. Significance of photointerpretation results in terms of macro-structure and micro-features and of the intra-urban regional core analysis by the interactive electronic techniques on the GEMS, correlating with ground truth at 1:24,000 scale, is discussed.

CONTEXT

Having appreciated, in anticipation, the vast potential of application of the novel form of data from the Earth Resources Technology Satellite, the design of a Data Utilization Experiment was developed by the present team of investigators with the following ingredients: an optimal sized, sufficiently complex test site; a multi-disciplinary application area; a cognizant, responsive user; sophisticated interpretation techniques and an innovative, coordinated team.

The Los Angeles Region has one of the most varied natural environments on the North American Continent, including a coastal basin, high mountains, a desert and channel islands. It shelters one of the most diverse and dynamic human settlements in the world, largely comprising the Southern California Megalopolis.

Regional planning focussed around a vast metropolitan area draws upon data from a number of earth sciences as well as social disciplines. With the increasing concern over the environmental impact of communal activity, the data needs of planners have become more comprehensive, accurate and urgent.

The Regional Planning Commission of the County of Los Angeles, in its Fiftieth Anniversary Year, recently submitted a Comprehensive General Plan as required by a State of California Law. A vast amount of data on a wide range of subjects had to be assimilated for completing through the second of three phases of this activity.

In addition to classical photointerpretation at the County, a major new development of an interactive electronic multispectral information extract systems at the General Electric Company provided a special thrust to this investigation. The versatility of analysis techniques, the flexibility of the hardware, the ease of operation and diversity of application modes and user products enable optimum use of capabilities of both man and machine to perform spatial and spectral analyses of remotely sensed data such as ERTS offers.

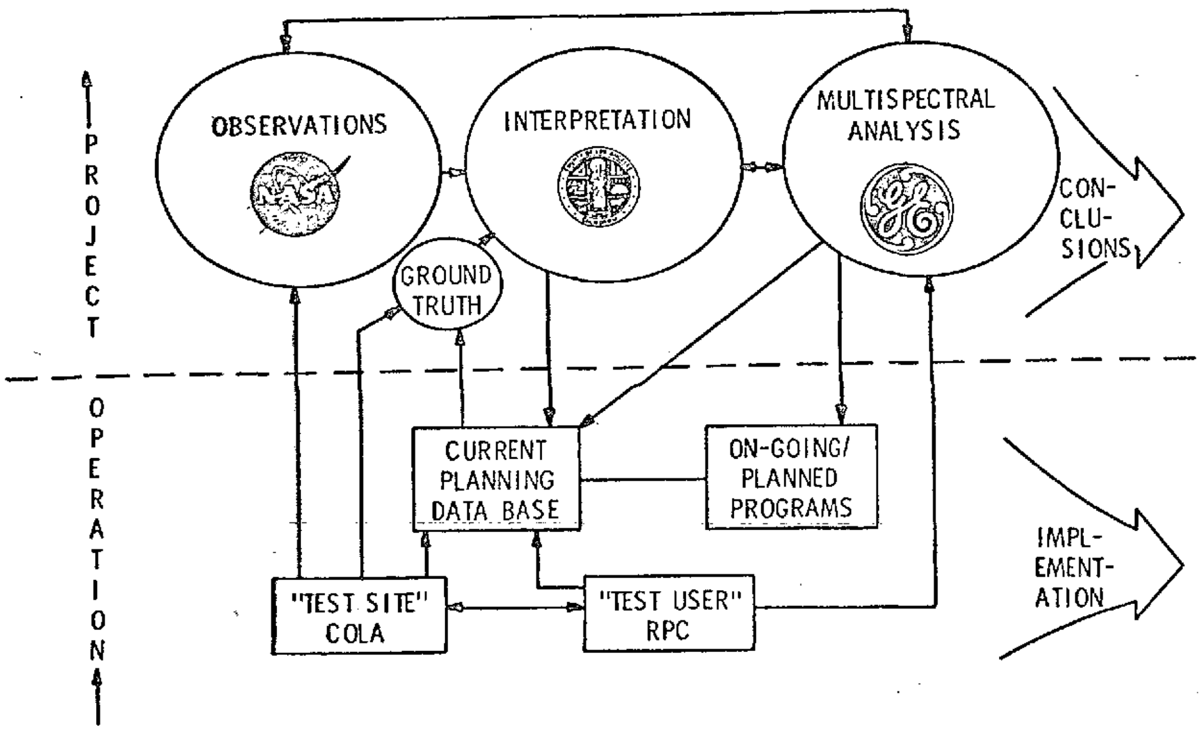


FIGURE 1. COLAGE Project Overview

The orientation of the team has been to approach the investigation in a non-preconceived fashion both with respect to the scope and the constraints of the ERTS data as well as the GEMS operation, critically evaluating the processes and methodologies used to arriving at whatever significant results, from the analyst-users' viewpoint, generated in the course of the effort. The nature of the investigation thus lends itself naturally to an appropriate balance between the management and utilization of ERTS data, consistent with the theme of this symposium.

SOURCE AND REFERENCE DATA

Primary Source Data Format for this investigation was the standard ERTS color-composite positive transparency both for visual and electronic multispectral analysis. Secondary use has been made of the 9.5" black and white positive transparencies from the four MSS bands, supplemented by color and black and white prints at larger scales up to 1:125,000 and 1:80,000 respectively.

Non-standard filter and band combination color-composities have been obtained for certain specific situations, from the GE Photoengineering Laboratory at Beltsville, with rather limited effort at their analyses. Temporal compositing of multi-color transparencies has also required the development of a new registration procedure.

Direct digital data, off the computer compatible tapes, has been used on the GSFC LARS terminal and GE IMAGE 100. An order of magnitude improved classification results compared with film input.

LA, CALIF., 21 OCT. '72, STD. COLOR-COMPOSITE BANDS 4, 5, 7

Reference data here designates such ground truth and quasi-ground truth data as has been used both for preparing inputs and in evaluating outputs of visual and electronic analyses. On a comprehensive basis, the earlier form of reference data base was the set of current land use and agricultural maps using the USGS quad sheets at 1:24,000 scale based on same scale imagery and direct inputs respectively already available at the County. Selective site visits and access to other agencies for specific items, such the water management agencies, provided the requisite data.

The most direct, up to date and accurate reference data was made available with the aircraft underflight imagery specifically flown by NASA-ARC in support of this investigation. Three such coverages in December 1972, March and July 1973 were made with respective sensor packages of Venten-RC10, A3 and A1 configurations with multiband black and white, color and color infrared imagery at 1:400,000, 1:130,000 and 1:32,000 scales. This data has been used in both pre- and post-analysis modes for input preparation and output evaluation respectively. In the terminology detailed further on, this range of data proved essential in corroborating the macro-, meso- and micro-scale results and conclusions arrived at during this investigation.

ANALYSIS TOOLS, TECHNIQUES AND PROCEDURES

Classical Photointerpretation of the ERTS imagery over the Test Site SR 124 has been primarily done at the County Planning Commission, principally by the Test Site Coordinator, basically using a low-power hard-held magnifying glass and a light table. The intensive knowledge about the ground scene obtained in the course of years of planning in the region was supplemented by specific reference to the sequential aircraft underflight imagery. The relationships and features so analysed can be characterized as macro- and meso-scales, providing much new insight into the regional context and urban structure respectively.

Electronic Multispectral Analysis facility, the General Electric Multispectral Information Extraction System (GEMS) is a user-oriented, interactive tool operated with a few hours of instruction. The GEMS analysis flow is shown functionally pictorially in Fig. 2. The input image can be a black-and-white or color transparency or, in Image 100, direct digitized data from a computer compatible tape up to four channels. The color CRT Display Module on which the image can be viewed serves as the principal output means which also permits simultaneous display of reference material as well as classified thematic results for user evaluation. The other output medium is magnetic tapes with both extracted signatures and thematic binary data recorded for subsequent reading in or printing out. Preprocessing includes radiometric correction, ratioing and transformation functions applied to image data (resulting in improved feature space representation). Transformed images can be analyzed in photointerpretation mode for manual processing or in signature acquisition mode.

PRINCIPAL ANALYSIS in operating GEMS comprise of training--viz. selecting an object/area for extracting spectral signature--and classification, viz. scanning the total image pixel (picture-element) by pixel to identify those which correlate with the selected object signature. The actual machine processing time for this entire set of operations is in fractions of seconds. In fact, the user can train, classify initial results, utilize spatial analysis and/or his knowledge of the scene to interpret any misclassification, modify the extraction algorithm and obtain new results - all within seconds.

The interactive, rapid response features of GEMS enable effective, efficient extraction of information from multispectral imagery through use of both spatial and spectral techniques. These include supervised

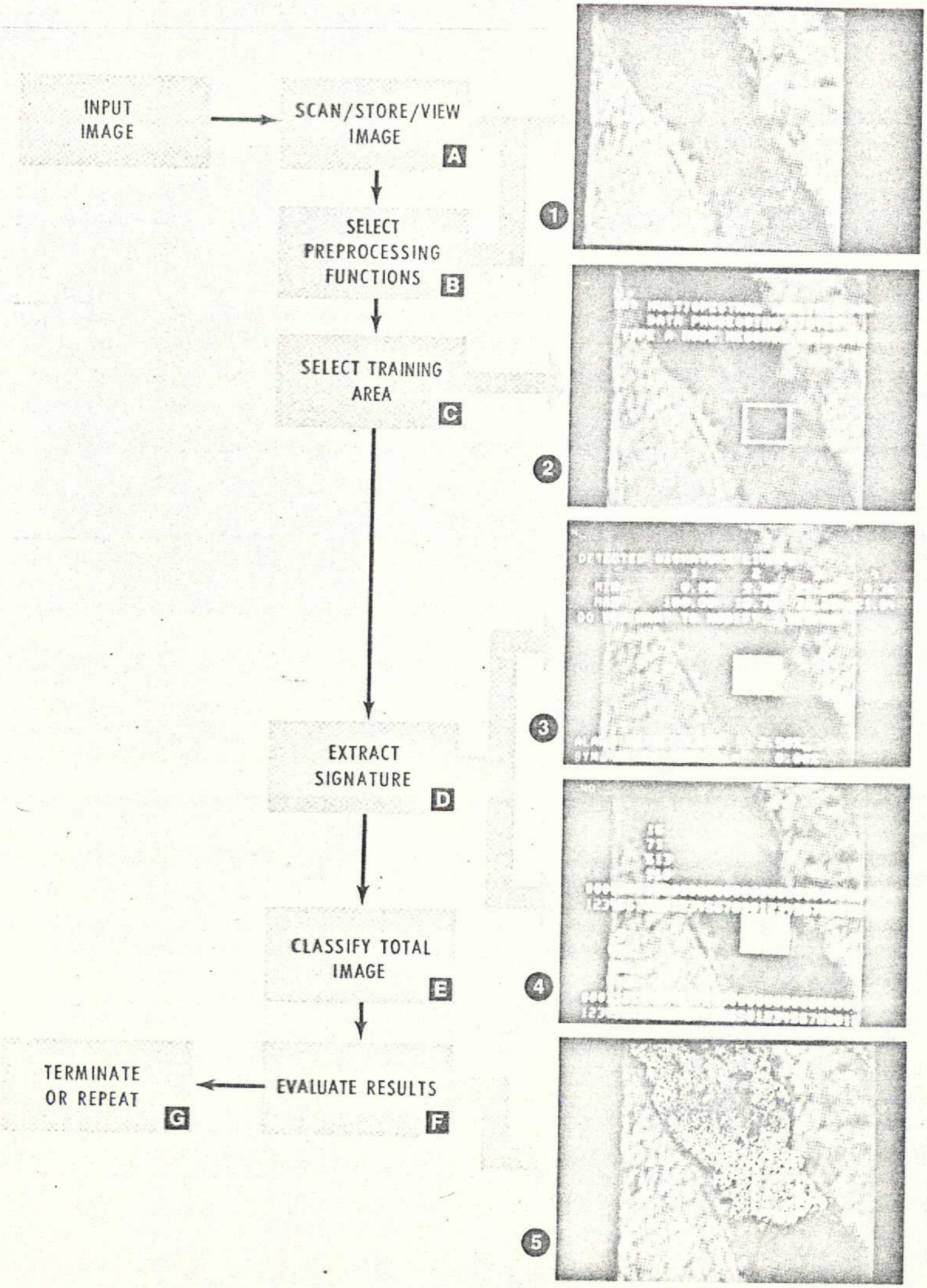


Figure 2. Typical Simplified GEMS Analysis Procedure

and unsupervised training (learning) clustering, factor analysis, parametric and non-parametric maximum likelihood analyses and variance and higher moment analysis (texture analysis). In this investigation so far, the first two of these have been used more extensively.

Machine Training Via Supervised Learning: Referrring to Fig. 2, the training site is enclosed within the cursor of photo 2. In extracting signature, four single-channel gray level distributions for the pixels within the cursor area are obtained and displayed as one-dimensional histograms. Photo 4 shows these for channels 3 and 4. The bottom numbers enumerate the levels 1-32 (this can be 1-256 in Image 100). The vertical numbers above each level represent the pixel count. From these one-dimensional histograms, GEMS determines the upper and lower limits of the spectral distribution in each channel. Photo 3 shows these as percentages of full-scale. These limits are modifiable. The four-dimensional parallelepiped described by the limits is the hyper-space containing the spectral cluster of the pixels in training area, defining its spectral signature. The four-dimensional histogram is then used for classification.

Basic modes in which supervised machine training is accomplished are:

Parallelepiped Mode
Interactive Mode
Histogram Mode.

The procedure just described when used simply as above corresponds to the parallelepiped mode. In the interactive mode, Fig. 3, the training

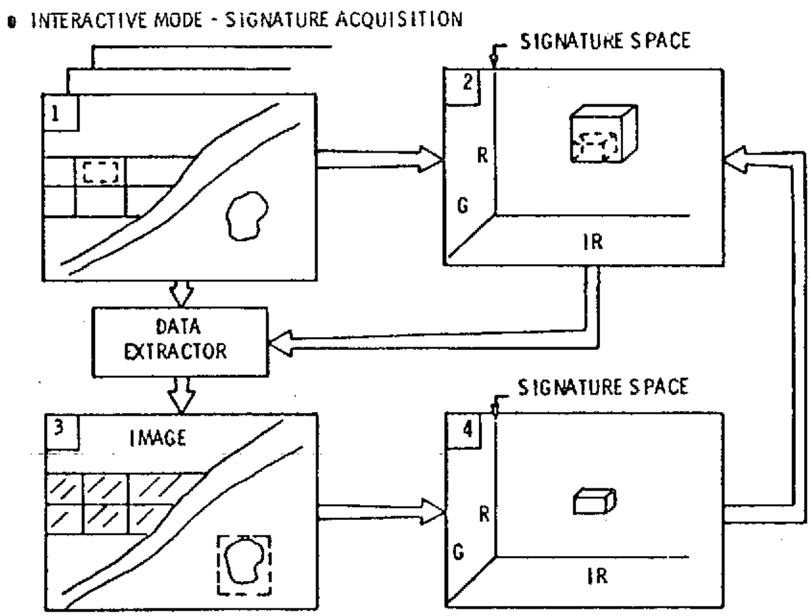


Figure 3. GEMS Interactive Mode for Signature Acquisition

area--Step 1--signature parallelepiped--Step 2--is obtained and sent to the extractor--Step 3--to test for like objects in the entire scene. With this initial gross approximation, if the user ascertains any false-ly alarmed area--Step 3, lower right--then its signature is generated--Step 4--and subtracted from the previous signature parallelepiped to leave the "L" shaped decision region--Step 2, modified--which is used to reclassify the input image--Step 3, modified. If the user originally finds from his knowledge of ground truth that certain area was not alarmed--Step 3--then he could add the signature of any such area--Step 4--to Step 2.--The process can be iterated till the user feels the composite signature has satisfied his test samples set.

In the histogram mode, Fig. 4, which is a semi-automatic operation, the hyperspace within the initial parallelepiped is sliced into many small parallelepiped subregions and the number of training area pixels in each

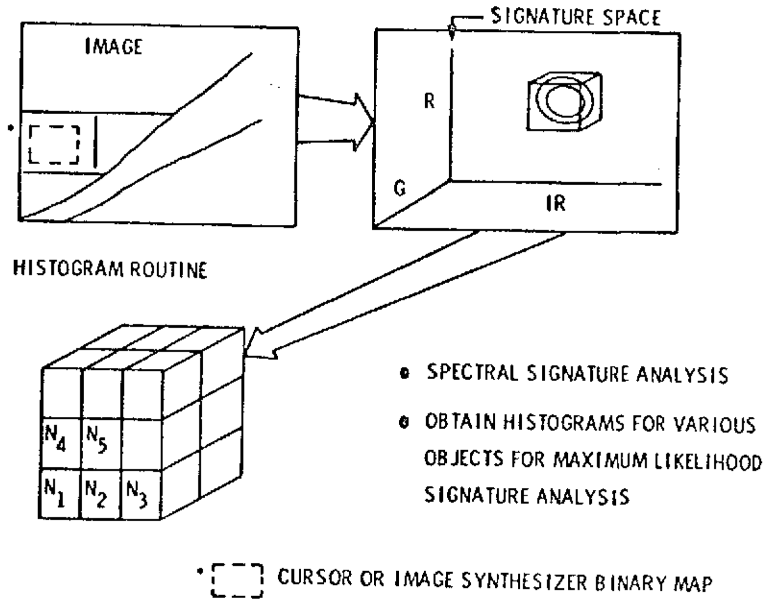


Figure 4. GEMS Statistical Signature Acquisition & Evaluation via Histogram Mode

cell is counted. The subregion boundaries and the individual pixel counts within the cells represent a four-dimensional histogram of the training area's signature distributions. Theoretical or empirical measurements can be made on these distributions.

CLASSIFICATION using the acquired training area signatures, with the same preprocessing functions, is accomplished across the scene segment within the display field of view. In the GEMS at Valley Forge, the minimum zoom covered about 1/5 x 1/5 of an ERTS 9.5" transparency, requiring some 25 traverses to classify an entire ERTS scene per theme. Ratio of maximum zoom is about 6. Signatures for more than one theme could be stored on a signature tape for subsequent use. Theme output for 512 x 512 pixels could be similarly stored on a theme tape. An off-line program could point up to 12 themes simultaneously on a theme map.

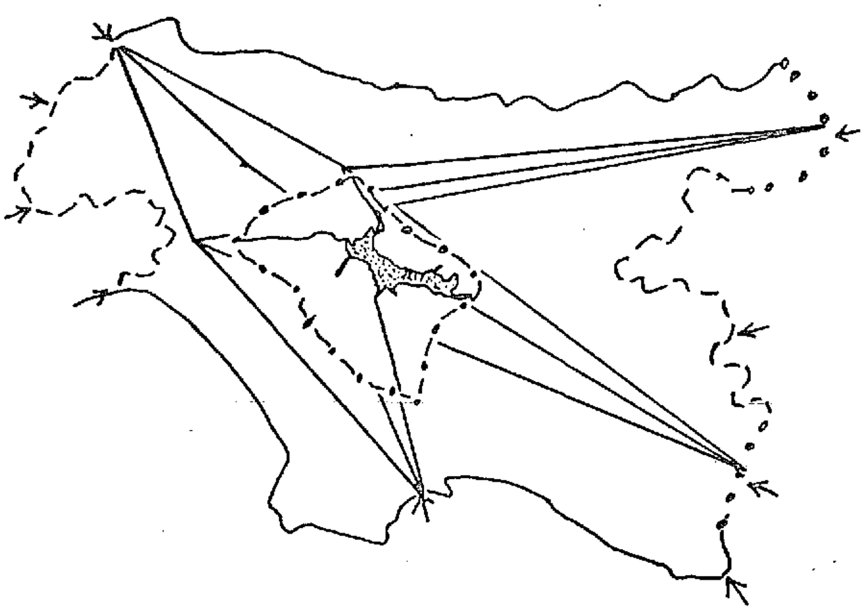
UNSUPERVISED learning technique used in the investigation so far has comprised of the multiple levels slicing-clustering in spectral space. In contrast to the previously described a priori, ground-truth-based training-testing method, the slicing-clustering approach is scene-content-oriented, resulting in a posteriori analysis. The entire field of view is analysed directly, sequentially either by progressing through a preselected sequence of level slicing or by grouping levels/cells in spectral space and evaluating the correspondingly displayed pixels on the screen from potential theme definition point of view.

INTERPRETATION of output results is necessarily more direct and immediate for the supervised learning runs while that for unsupervised learning runs (while that for unsupervised learning cases) is relatively less straight forward. Iteration of runs within the same group or in a mixed sequence, starting with either mode can be made to arrive at convergent results. Each of the output formats have certain advantages: the slides of the combiner TV screen can be obtained with the scene background for ready and accurate reference. While the computer printouts enable comparison and even regrouping of a large number of themes simultaneously.

SUMMARY OF RESULTS APPLICABLE TO REGIONAL PLANNING AND URBAN DEVELOPMENT

Characteristics of ERTS Data, such as synopticity, periodicity and multispectrality offer regional planners for the first time a uniform view of a large area without needing mosaicing, dynamic observations for monitoring and trend prediction and a comprehensive insight into intra- and inter-relationships. This unconventional new data source calls for innovative uses and applications. An overview of the scope of ERTS data utility for planning will be briefly taken up later. Here a few examples of the application of analysis techniques will be given, ranging in generic scales: macro-, meso- and micro-features.

Visual Analysis of ERTS scenes over Los Angeles brings out very vividly the macro-form and structure of the metropolitan region: diagramatically represented in Fig. 6. The urban perimeter, some 225 miles in



Scale = 1:1,000,000

—— Stable Edges, ----- Nearly Stable Edges; ..... Unstable Edges; .--. Inner City Boundary High Intensity Core; ——> Major Approaches

Figure 6. Macro-Form and Structure, Metropolitan Los Angeles

length can be classified into stable, nearly stable and unstable segments lying against powerful natural boundaries. The urbanized area, of varying hues of blue-greys, can be fitted by an ellipsoid. The inner city of Los Angeles can be bounded by a quadrilateral elongated in a northwest-southeast direction. The high intensity core has an "X" shape, the LA central business district lying at about the intersection. The approach corridors to the metropolis appear at natural passes and breaches: eight major landward and one seaward. The fact that Los Angeles is against or near natural boundaries along more than 90 per cent of its edges indicates that major lateral growth and spread of the metropolis is near an end. Further growth of LA will occur largely as intensification of the already urbanized areas.

Internal structure of Metropolitan Los Angeles can be discerned visually by delineating the smaller scale features to a level of detail depicted in Fig. 7.

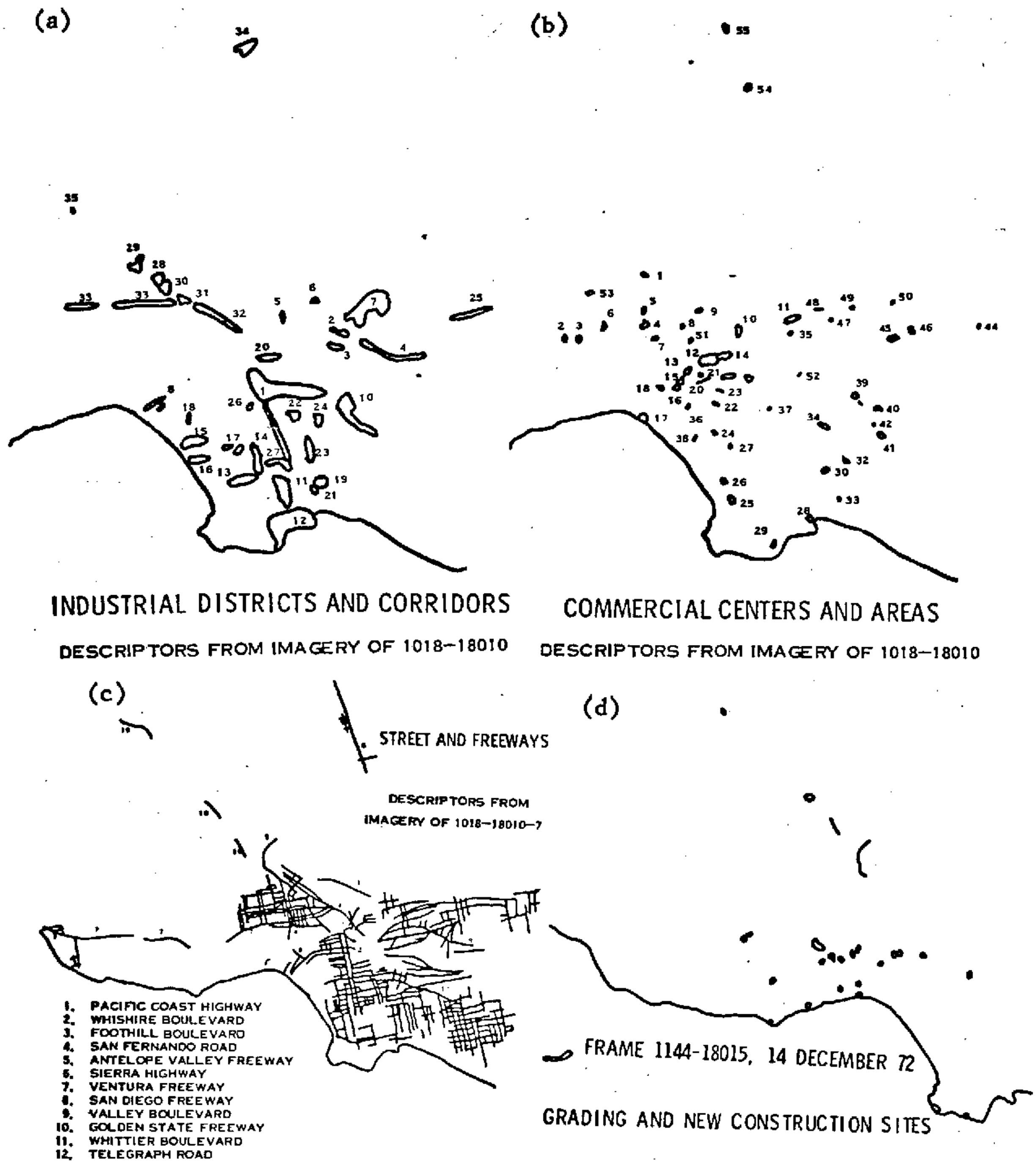


Figure 7. Meso-form and Features of Metropolitan Los Angeles

The major industrial districts, Fig. 7(a), visible in ERTS imagery at 1:1,000,000 scale, bring out two broad patterns: a radial one, emanating from central Los Angeles, and an axial one, extending from Los Angeles - Long Beach harbors to the Los Angeles International Airport. On the other hand, the pattern of commercial centers, Fig. 7(b), is widely dispersed - with a noticeable gap in central and south central Los Angeles, indicative of a commercial services deficienty. Fig. 7(c) shows segments of about 190 major streets and freeways from the MSS Band 7 transparency at 1:1,000,000 scale. The street pattern seen here provides one basis for dividing the urban area into subregions for further planning studies. Fig. 7(d) shows a few grading and new construction sites. The significance of being able to discern such sites and even detect change in them in successive cycles is that ERTS imagery makes it possible to monitor the extent, rate and direction of urban growth.

Regional relational features could be illustrated by the examples in Fig. 8. An analysis of the (4,5,6) bands composite of the Dec. 14, 1972 scene, Fig. 8(a), by the test site coordinator led to the tentative identification of a new major fault lineament in the northern slopes of the Santa Monica Mountains. This finding, with much planning implication, is being evaluated by the county geologist and the State of

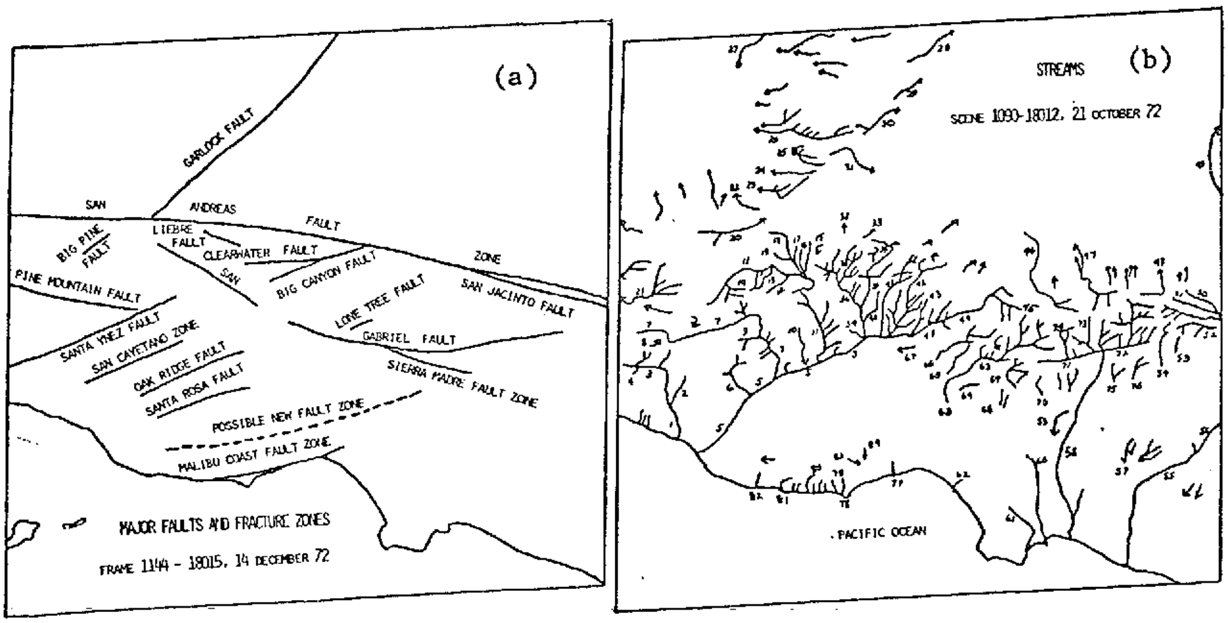


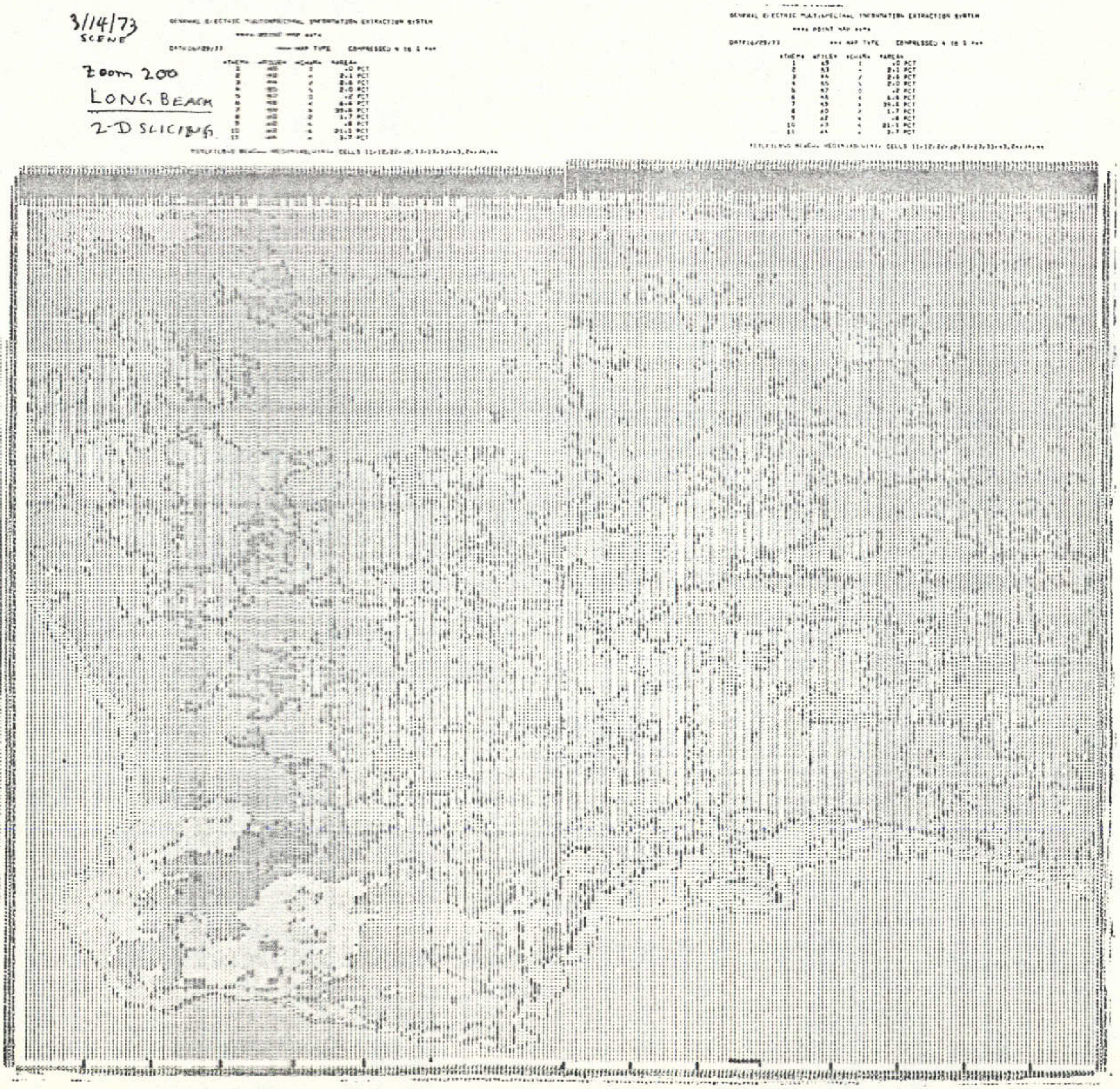
Figure 8. Regional Relational Features

California Division of Mines and Geology. The two major natural drainage systems in the region, one draining to the Pacific Ocean and the other to closed basins in the Majave Desert, are shown in Fig. 8(b).

Other overlays prepared from the 1:1,000,000 scale ERTS transparencies, too numerous to reproduce here, include such topics as: major natural provinces, planning regions and sub-regions, selected topographic features, minor land forms, reservoirs and lakes, snow cover, grass growth, brush fire burns, major agricultural areas, etc., refining the regional perspective. The data range and depth of 1:1,000,000 scale ERTS transparency exceeds that on a 1:250,000 scale plastic relief map in the AMS series. Of course, the dynamicity of the data inherent in cyclic ERTS imagery is missing in usually available maps. The seasonality of data obtained from ERTS was an element planners could not afford previously, though it has direct applicability to many elements in a comprehensive general plan.

ELECTRONIC MULTISPECTRAL ANALYSIS OF ERTS imagery has been one of the major aspects of the investigation. Only an overview of this activity is possible to present here. As pointed out before, runs or experiments can be made rather rapidly on the GEMS while evaluation of the output is a much more time-consuming activity, application of the results being even more so.

Both supervised and unsupervised learning runs were made in parallel throughout the investigation, though here the latter would be best grouped and discussed first. Single channel slicing initially began with four-level/quartiles in the red channel, later done with 10 to 15 level slicing in each red, blue, and green channels. Two channel runs similarly ranged from 4 to 10 level slicing in redxblue, redxgreen most commonly, occasionaly blue-green.Three channel runs:4x4x4, 10x10x10 too.



Unsupervised Learning Example:
Red (4) x Blue (4) Slicing over
Long Beach

Geographically-topically, the urban core of central Los Angeles was the focus of much of unsupervised analysis. However, equivalent runs over other regions, notably Long Beach, San Fernando Valley and San Gabriel Valley, were made. Figure 9 shows the composite plot of some 11 out of 16 cell-themes obtained for 4 x 4 red x blue slicing for the March 14, 1973 scene. Even though the shoreline helps reference the plot to a map, analysis is facilitated by color-coding the plot and super-posing a street-grid and other planimetry for referencing.

Characteristically, the conventional themes such as land use categories like water, open space, residential, commercial, industrial areas, etc. fall within fairly narrow spectral slices. A repeatable sequence of the themes from the less to more dense/intense vegetative/man made ground cover emerges in a typical run.

Temporally, while unsupervised slicing-clustering runs were made for a number of cycles between 1 and 13, controlled sets of one, two and three channel slicing with step-wedge calibrations over equivalent intervals were made for the October 21, 1972 and March 14, 1973 dates. These scenes were chosen both for having the farthest seasonal interval and comparable sun-angle illumination conditions.

For example, in the general class of parks, golf courses, cemeteries, distinction among the subclasses is possible if the two cycles of imagery are used. Golf courses are typically maintained at a relatively constant level of condition throughout the entire year and thus appear as relatively constant features spectrally. Parks, on the other hand, are more subject to seasonal changes and the variations of natural watering. They thus exhibit an improvement in general condition between the October imagery and that obtained in March. It is important to distinguish among these subclasses as different private and public management organizations are concerned with each. And this set of data forms a sub-set of the requirements of the State of California Water Resources Department in their compilation of water-related land use.

Combined spatial and temporal analysis underway is permitting better discrimination in the substructure of the individual subclass sites than can be obtained with a single image. The results will be useful in, for example, park quality assessments undertaken by the Parks and Recreation Department of the County.

The all-digital IMAGE 100 runs using computer compatible tape inputs in addressing the same problem obviate the photoprocessing and system errors present in film: digital input from the two cycles can be read into a disc memory and read off for simultaneous processing, up to two bands each, and analyzed interactively either superpositionally with the full-screen or parallel with the split-screen format.

SUPERVISED LEARNING - Training and Testing Method - This series of runs made so far could be grouped into two categories based on the type of input preparation: a) scene-obvious training and testing sites; b) aircraft or ground data referenced training-testing areas. In the terminology becoming more prevalent since its use in the USGS Circular 671, the former class, a), would be generally Level I training-test areas while the latter, b), class would be drawn from Level II or more detail of definition.

Topically, scene-obvious theme runs covered:

i) Surface Water Bodies,
ii) Agricultural Fields,
iii) Grassy Growth,
iv) Snowy Areas,
v) Alluvial Fans,
vi) Dust Storm Trails,
vii) Parks-Golf Courses-Cemeteries,
viii) Grading-Construction Sites.

Even though the input is broadly characterized as being scene-obvious, often certain tonal and textural fine-structure could be readily discerned over the training site, within the cursored area, which required referencing to aircraft imagery or ground data for discrimination. The output, especially in the histogram mode, necessarily required aircraft or ground data for detailed evaluation.

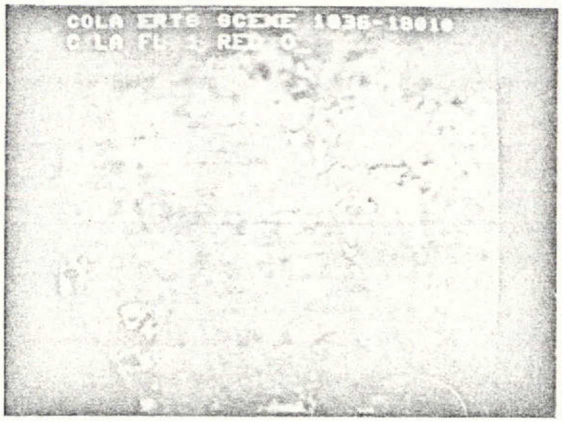
The group of runs for which more detailed input itself is necessary, either having sufficiently exhaustive knowledge of the ground scene or aircraft imagery of sufficient resolution, was made for the following broad classes:

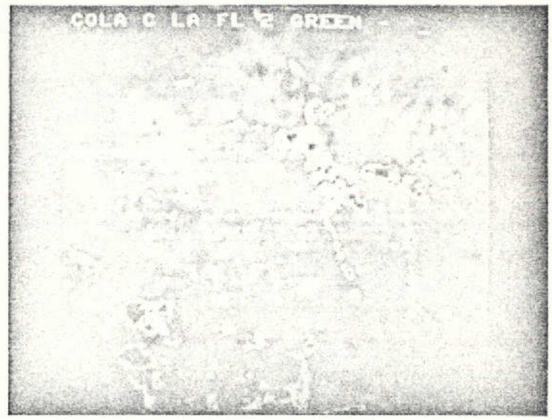
1) Residential Housing Areas,
2) Commercial Business Districts,
3) Industrial Centers-Corridors.

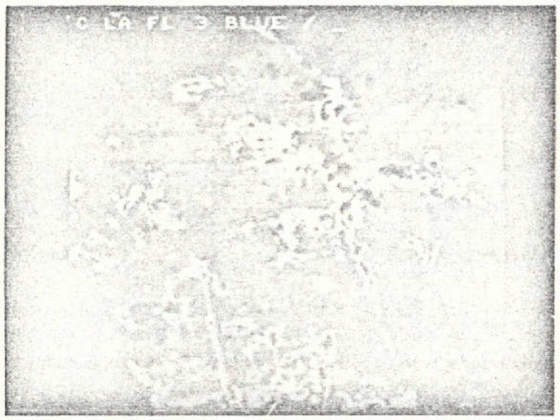
The 1:32,000 scale imagery from the A-3 configuration flown on March 14, 1973, enabled sub-classification of the input. Thus, within the residential areas, housing types such as single home communities, apartment complexes, mixed configurations, etc., could be selected for signature acquisition. Using these signatures in the immediate neighborhood as well as in comparable communities elsewhere in the scene seemed to enhance areas which fell within the same housing types as preliminary inspection of the results compared with the aircraft imagery showed. Single family area classification was somewhat more homogeneous; while apartment signatures picked up multi-unit complexes, occasionally including marginal portions of newer commercial areas. Training on commercial districts and industrial centers generally yielded plausible patterns. Further evaluation is underway.

HYBRID OR ITERATIVE application of the supervised and unsupervised learning is possible by simultaneous or successive use of these techniques. One such experiment on the GEMS which has been analyzed in some detail would be appropriate to duscuss here: segregation of land cover in central and western Los Angeles metropolis. The GEMS run was made in the manual, parallelepiped mode on an early, 8/28/72, scene before receiving any underflight aircraft data. It was proposed to cover the range of themes in seven steps, varying from the intensely used inner city to public open spaces like golf courses and parks. Themes 1 and 7 were thus generated with appropriate training-testing sites: Figure 10 (i) and (vii).

The intermediate themes were generated by incrementally extending the signature thresholds to successive settings until certain photomorphic or tonal regime was being enhanced: Figure 10 (ii) and (vi).







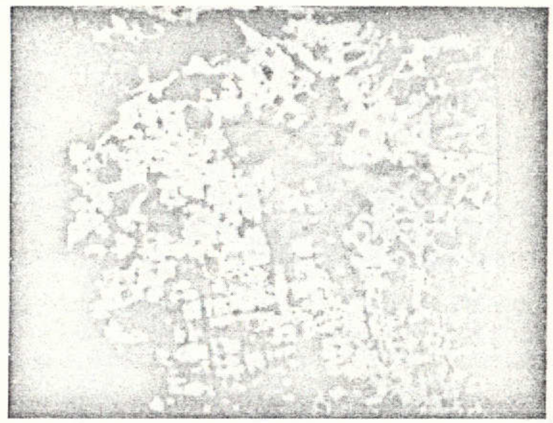
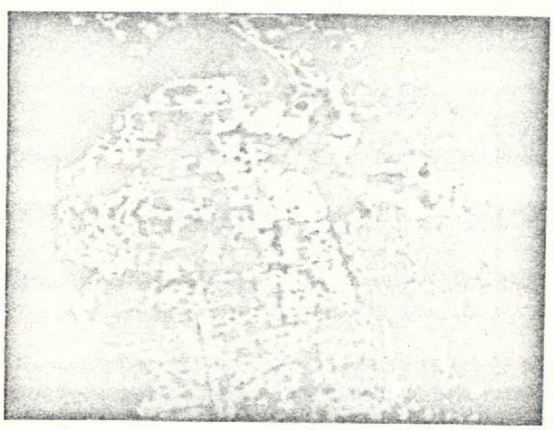
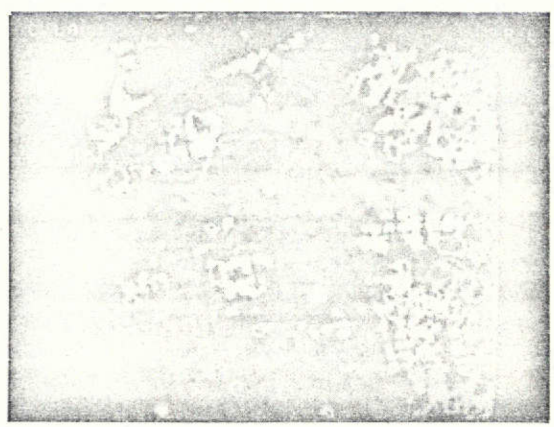
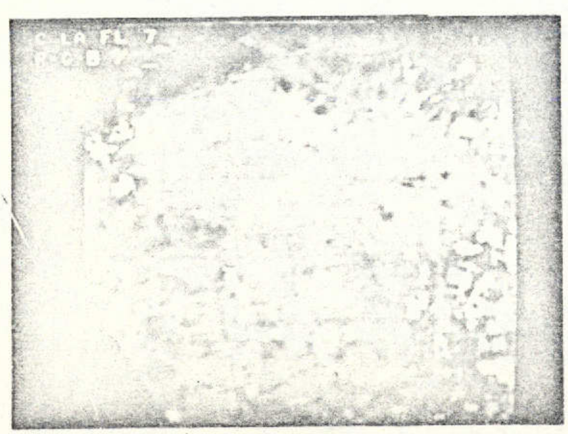





Figure 10 : (i) , (ii)
(iii), (iv)
(v) , (vi)
(vii)

A Seven Theme Sequence of
Land Cover Segregation in
Western-Central Los Angeles

Sequentially, Theme 1 predominantly comprises heavy industrial facilities and intensive commercial district structures in central Los Angeles. Almost 100% of this class is covered by artificially modified surface with no natural vegetation cover. Theme 2 covers medium industrial and commercial centers, with close to 90% composed of buildings, structures and pavement. Theme 3 yields strip commercial areas and fine-textured apartment areas, while Theme 4 develops primarily intensively developed apartment areas. From 50 to 90 per cent of land in Themes 3 and 4 is covered by structures and pavement. The first four themes combined define a high intensity urban region lying west of a general line delineated by Alameda Street and San Fernando Road.

Extensive areas of single family housing constitute the dominant element of Theme 5, much of it developed prior to 1940. Theme 6 shows scattered areas of high quality single family housing while Theme 7 covers upper income residential areas and wide range of open space features including golf courses, parks and ceneteries.

Superposing the above seven themes in a multi-le-exposed, multi-colored transparency, the original of Figure 11 was obtained. Each theme was interpreted by projecting the GEMS-derived slide onto the current land use map of the area at 1:24,000 scale, as shown in Figure 11. The thematic and geometric accuracy with which this corroboration of GEMS-extracted analysis was possible at this large a scale is extremely

Figure 11. Superposition of the Seven Themes from Figure 10. Original Multi-Colored.

Figure 11 :Current Land Use Map with area included in Figure 11. Mylar overlay from Fig.10. Original colorcoded Scale 1 : 24,000 Operating scale at Regional Planning Commission of the County of Los Ang.

significant. A closer examination of Figure 11 shows that certain transition areas, appearing as overlap between neighbouring themes - as between 1 and 2, 4 and 5 - delineate subclasses. Areas unclassified in the set of Fig.10, such as the salt and fresh water surfaces and the largely unurbanized hilly land have been differentiated in other runs.

Since making this early set of comprehensive runs to segretate land cover in central-western Los Angeles metropolis , sub-classification of individual broad themes delineated in these runs has been accomplished for residential, commercial and industrial areas using the next finer level of input delineation -- aircraft imagery defined -- as well as analysis level -- histogram mode.

The procedure of first sub-classifying to the maximum detail possible and then aggregating the finer-level categories into a coarser level composite pattern[1] will be applied to reconstruct a more accurate land cover segreagation - use intensity map of the type described above. Such a map reflects the general quality of the environment and aspects of the general regional ecology of the area under study, both having major policy implications for regional planners and managers. The primary application of the analysis in the urban area is seen to be in the field of urban design. In the thematic map just viewed, a complex nodal structure has been defined and major traffic channels are recognized. Open space are recorded; edges and boundaries are delineated and their strength is hinted at by the closeness of the thematic contours or isarithims ; texture and grain are reflected. These data items are indeed the meat of urban design.

ERTS-GEMS dramatically extends the hithertofore limited capability of planners to attack problems of metropolis-wide design. Complementing such intra-urban analyses with those of suburban and outlying regions , the capabilities demonstrated here are enough to radically alter the conduct of planning operations by regional, state, national and international agencies concerned with urban development, regional planning and environment management.

[1] Land Use and Mapping , Summary by D. Wayne Mooneyhan in the Symposium on Significant Results Obtained from ERTS-1 , March 5-9, 1973; GSFC-NASA X-650-73-155, VOL. III, P. 23 .